Guide 73

Energy efficient house design – exploiting solar energy

Houses that exploit solar energy do not need overlarge windows on the south side but, like the north face of this house, are designed to reduce heat losses on the north. They look much like other houses but have a market advantage.

Solar energy and housing design

Sunshine is the most environmentally friendly renewable energy source. It is freely available throughout the UK and, on a seasonal basis, the quantity of solar radiation received at a particular location is fairly predictable. All buildings are exposed to solar radiation, and solar gains in buildings are a well-known phenomenon. Through an understanding of the potential of solar energy at the design stage, it can be exploited as part of an energy efficient design strategy.

In existing dwellings solar energy contributes to the total energy used – as daylight and also as heat. Estimates put the extent of its contribution towards space heating in typical houses at 10-15%. Through careful attention to the siting of houses, and their form, fabric and services, it is possible to increase the benefit from sunshine. This will help to conserve conventional fuels and protect the environment.

Integrated energy efficiency measures

Sunshine and daylight are best utilised as part of an integrated approach to energy efficient building design embracing siting, layout and orientation, building form and internal arrangement, building fabric and building services. When designing to benefit from solar gains, care should be taken to ensure that other aspects of energy efficient design, particularly minimising heat losses, are not compromised.

Key points for designers wanting to exploit solar energy are summarised in this Guide, which draws much of its material from a new comprehensive design manual called "Solar Energy and Housing Design" written and published by the Architectural Association School of Architecture (AA). This two volume manual has been sponsored by ETSU as part of the DTI's Passive Solar Research Design and Development programme, and is profusely illustrated with line drawings and photographs.

Key issues for designers

- Solar energy should be exploited within an integrated energy efficient approach to house design.
- The approach should include traditional energy conserving measures such as compact plan forms, high levels of fabric insulation, and well controlled heating systems.
- Solar potential should be considered at all levels in the design process – from site planning to house orientation, and from internal arrangement to specification of components and services.
- Site layouts should be planned to reduce overshadowing of windows by other dwellings and obstructions.
- Living rooms and bedrooms should be located on the south to benefit from solar gain.
- Over glazing should be avoided: optimal designs do not need large areas of glazing, nor need they look exotic. It is the distribution of glazing that is important.
- Wherever possible – subject to normal requirements for daylight and ventilation – glazing should be redistributed from north, east and west facades to south facades.
- A responsive and well-controlled heating system is essential to ensure that solar gains lead to reduced fuel use.
- Glazed features such as conservatories are of limited potential for heating houses by solar energy. If they are heated by a radiator or by warm air flowing out of the heated part of the house, they will raise fuel consumption rather than reduce it.

Energy Efficiency Office
DEPARTMENT OF THE ENVIRONMENT

"Solar energy is the most environmentally friendly energy source, and costs little or nothing to exploit when integrated into energy efficient house design"

How solar energy reaches buildings

The solar radiation to which a building is exposed is made up of three components:

- direct beam radiation from the sun
- diffuse radiation from the sky
- reflected direct and diffuse radiation from the ground and other surfaces.

The direct component is the most variable. It falls to zero if the sun is hidden from view by clouds. When this happens on cloudy winter days the total amount of radiation is too small to contribute significantly to space heating. On average and clear days, however, the total radiation is strongly related to the orientation of the building and its view of the sun. At these times solar energy can contribute to heating.

Orientation and latitude

The sun-path diagram (figure 1) shows the position of the sun, in terms of altitude and azimuth, relative to an observer facing south, at various times of the year in Southern England. It can be used to assess the potential of sunlight to reach facades of a building, and the effect of overshading from neighbouring buildings, trees, and projecting parts of the building itself. Sun-path diagrams are specific to particular latitudes: as latitude increases the maximum altitude of the sun is lower (by one degree for each degree of latitude) and the winter day length is shorter.

The magnitude of direct radiation is greatest on a plane which is at right angles to the sunbeam. Of all vertical facades, south facing ones receive the most sunshine, being potentially in view of the sun all day during the heating season. East and west facing facades potentially see the sun for only half the day. North facing facades see very little of the sun, and then only in the summer. Figure 2 shows the amount of incident solar radiation available to different dispositions of glazing between the various orientations.

Sunshine and glazing

When solar radiation strikes glazing it is partly reflected, partly absorbed and partly transmitted to the interior, in proportions which depend on the properties of the glass. Of all glass types, clear single glazing transmits the most solar radiation, but it allows more heat to be lost than multiple glazing so it is important to consider the ***energy balance*** between solar gains and heat losses (see figure 4).

Reflection, transmission and absorption of direct sunshine vary according to the angle at which the rays reach the glass. Transmission is greatest when the rays are at right angles to the plane of the glass. In summer, the higher altitude of the sun narrows the angle between the direct radiation and ***south facing*** windows. This prevents a peak in transmitted direct radiation through southerly windows from occurring during these months (see figure 3). Conversely, transmission through sloping glazing, such as that in a conservatory roof, reaches a high peak during the summer and frequently results in overheating. West facing glazing also receives peak irradiation in the summer months when solar gains may be unwanted owing to the risk of overheating.

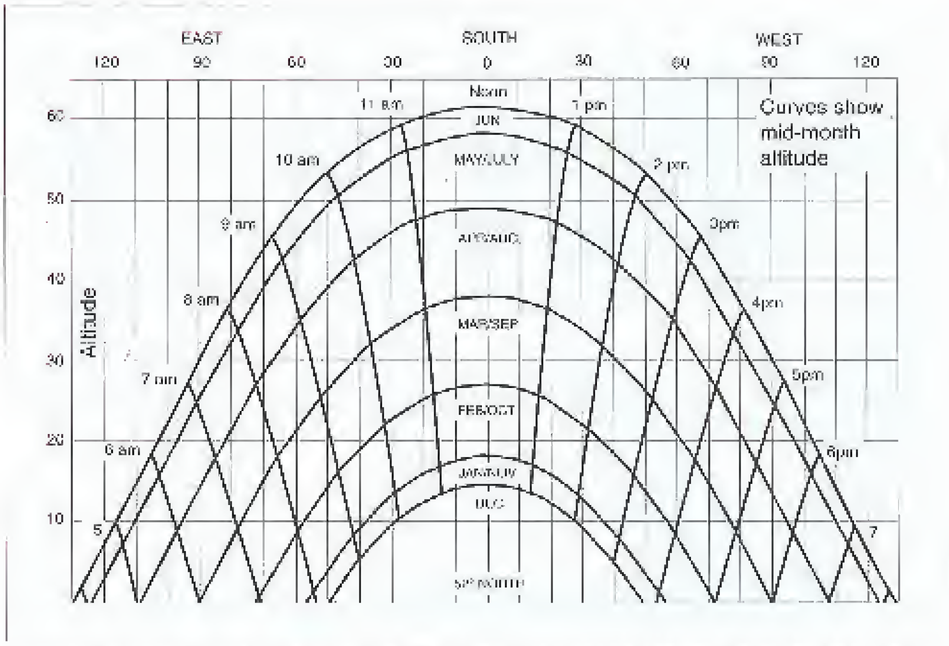
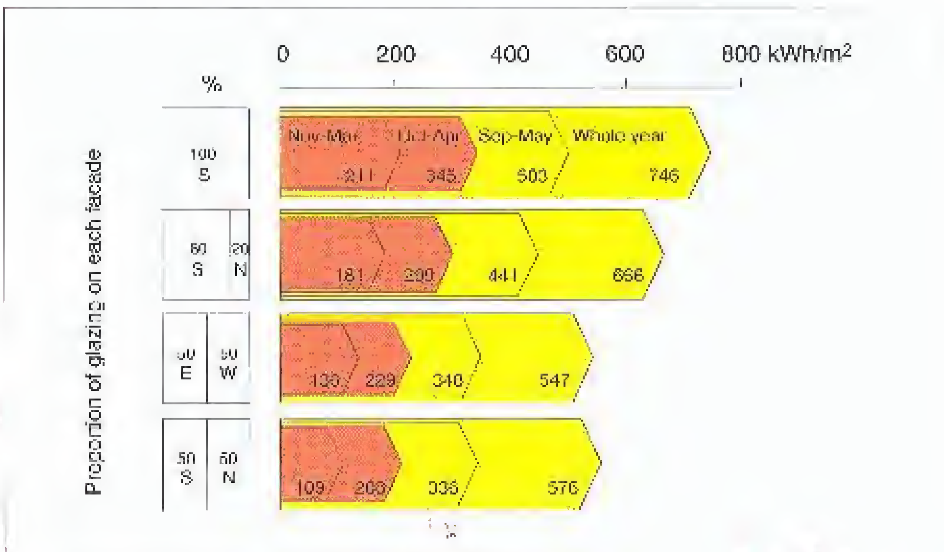
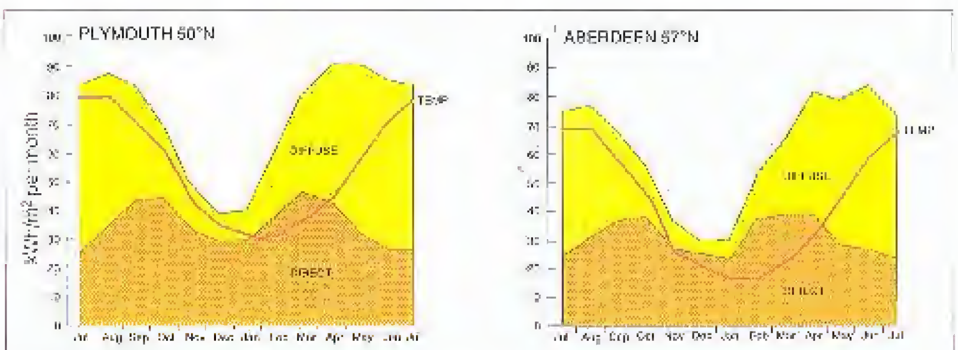


Figure 1 Sun-path diagram shows position of sun throughout year and enables designer to plot shadows from obstructions.



Source: Solar Energy & Housing Design – Architectural Association

Figure 2 Incident solar radiation (direct and diffuse) for four permutations of window distribution between different elevations (London).



Source: Climate in the UK – HMSO

Figure 3 Solar radiation on a south facing window and average external temperature. Direct radiation peaks occur in spring and autumn because the sun is at a lower angle than it is in summer. On east and west faces the peak occurs in summer.

The energy balance of glazing

In terms of heat losses, windows are a weak spot in the insulation of a house. The rate of heat loss through even double glazing is six times the loss through a wall insulated to the minimum levels of the current Building Regulations – assuming a U-value of 2.7 W/m²K for a window and 0.45 W/m²K for a wall.

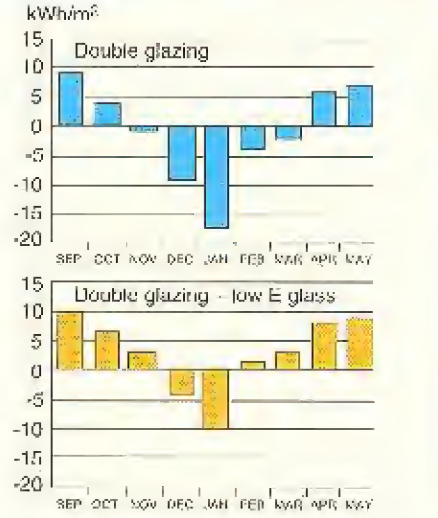
However, the heat losses are partly offset by solar gains through windows. The greatest offset will occur in windows which maximise access to available sunshine. The relationship between the losses and the solar gains represents the **energy balance**.

Because heat losses through a window vary according to external temperatures, they are greatest in mid-winter. Conversely, solar gains vary according to sunshine availability. Therefore the energy balance of a window varies; it is most often presented on a monthly basis.

As a general rule the following applies to **unobstructed** windows:

- for any window the best orientation is south, followed by east and west roughly equal, and with north the least favourable
- single glazing is a net loser of heat for all orientations during the heating season
- double glazing facing south has an energy balance that is almost neutral: the gains during the spring and autumn nearly equal the losses during the winter (figure 4)
- low-emissivity double glazing facing south has a net positive energy balance, during the heating season.

Overshading worsens the energy balance reducing, or even eliminating, the benefits of southerly orientation.



Source: Solar Energy & Housing Design – Architectural Association

Figure 4 Comparison of the energy balance of south facing double glazing with and without low emissivity glass (Sheffield).

House form: compactness and insulation

The main priority should be towards minimising heat losses. This can be achieved by ensuring the surface area of the envelope enclosing the dwelling is as small as possible, and by using high levels of insulation for all exposed elements. The principle of reducing heat losses through compactness and insulation should not be compromised in an attempt to increase solar gains: additional solar benefits seldom compensate for higher heat losses.

Window specification and size

Windows should be double glazed or better. Frames should be specified to minimise losses from draughts especially when the site is exposed.

There are more benefits to be gained from decreasing the size and number of north facing windows than by increasing south facing ones. Windows on north facades should be of the minimum dimensions consistent with good daylight and ventilation. If their size is so reduced that additional artificial lighting becomes necessary, any benefits from heat conservation will be entirely eliminated – or worse, turned into an energy penalty – by increased electric light usage.

South facing windows do not need to be increased in area; those of conventional or modest size are sufficient to provide the optimum solar gains. Enlarged areas may be feasible where there is good solar access but, in other locations or where houses are highly insulated, enlargement may increase heating demand. In very highly insulated houses the useful contribution from solar gains tends to diminish the larger the window area, while the risk of summer overheating increases.

Thermal buffering

Unheated spaces, such as garages and draught lobbies (and conservatories – see box) are valuable as thermal buffers to reduce the temperature drop across the walls bounding the heated dwelling. Separating walls should always be insulated. Thermal buffering of windows and external doors is more valuable than buffering highly insulated walls. Daylight, ventilation and means of escape, particularly where a conservatory is being planned, should not be compromised.

Semi-detached, terraces and flats

These forms of development benefit from thermal buffering. Heat flows between adjoining dwellings are usually considered to be low or negligible.

Room arrangement

Solar gains are likely to be most useful in rooms which have the highest heating demand, such as living rooms. They may be less desirable in rooms where there are other incidental gains, particularly kitchens, owing to the risk of occasional overheating.

Rooms with a lower heating demand and in which small windows are acceptable, for example WCs, bathrooms and circulation spaces, are preferably placed on the northern side. Well heated rooms should be planned adjacent to one another.

Heating systems and controls

Heating systems and their controls should be responsive to solar gains to ensure the gains are realised as fuel savings. Thermostatic controls in each heated room will help to achieve this. Separate zoning of ground and first floor rooms will allow each zone to be heated to its own time schedule.

Conservatories and energy use

Conservatories are highly visible features widely believed by designers to benefit the thermal performance of a dwelling. In practice, even under favourable conditions, this benefit is likely to be very small and will never repay the construction cost. If a conservatory is heated by occupants as though it were an everyday part of the house, it will add considerably to fuel bills.

Conservatory temperatures are generally too cold for comfort during much of the heating season, being typically about 5°K above ambient, although they are higher at times of direct sunshine. The raised temperatures provide a degree of thermal buffering of the elements covered by the conservatory but it is still essential to insulate those elements.

Even at times of direct sunshine during the heating season, the temperature of the air in a conservatory is rarely sufficiently above the demand temperature of the house for it to be used to heat the dwelling. Using this air as pre heated ventilation air is a theoretical possibility (although the humidity of the conservatory air should be considered) but it is not easy to move it into the house by passive means. Nor is it likely to be cost effective to use a mechanical system to do so.

Many conservatory owners are known to heat them for use as living space, either by opening the interconnecting doors or by having a heat emitter installed. Keeping a conservatory at normal demand temperature all year round uses about as much energy as heating a small house.

A conservatory should not be regarded as an energy saving feature.

Siting and site layout

The potential benefits from solar gains are largely determined in the course of siting and layout design. Sites should be planned to permit solar access for as many dwellings as the constraints of the site allow. This can be achieved by placing taller buildings to the north with lower and low density dwellings to the south. Roof pitches may become critical at close spacing.

Up to densities of about 35 houses per hectare, the number of houses on an estate that has been planned to benefit from solar gains can be the same as for any other estate. Above this number it becomes difficult to ensure that the benefits from solar gains are not increasingly reduced by overshadowing.

Windows of quite modest size are sufficient to provide useful solar gains and these can be fitted into narrower frontage houses. This makes it easier to incorporate passive solar design into a housebuilder's existing portfolio of plans or to develop new ranges that match their characteristics. Further studies are being undertaken as part of the DTI's Passive Solar programme to improve guidance on estate layout.

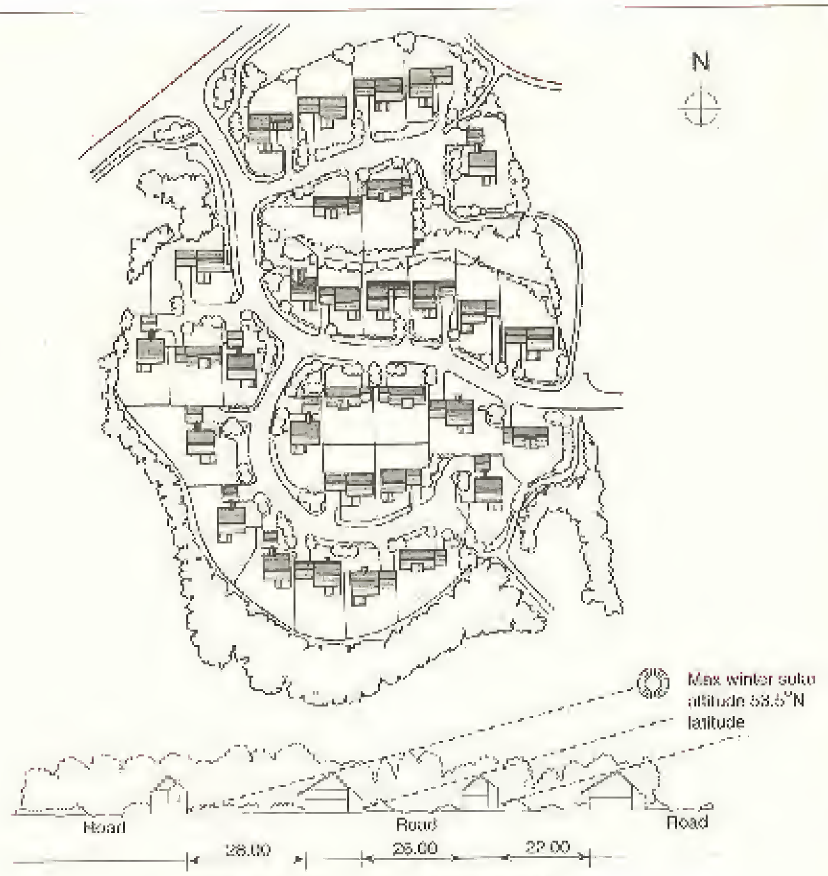
The AA's "Solar Energy and Housing Design" manual provides tools and data to assist with determining house spacing, and includes case study examples of site layouts.

Orientation and appearance

The main glazed facades of houses should be towards south where possible. Deviations from true south up to about 30 degrees east or west of south incur little loss in solar gains, but beyond this the solar benefits begin to reduce.

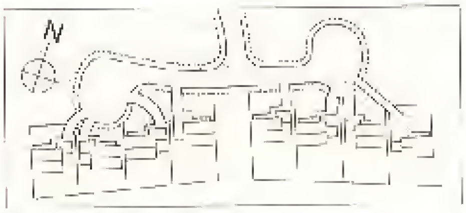
The appearance of uniformity on a site where passive solar houses have a bias towards the south can be overcome by careful attention to the selection of house types and their location and deployment on site. Ways of doing so include handing, alternating different types, the composition of secondary elements such as garages, setting houses forwards or backwards in their plots, and varying orientation between 30 degrees either side of south.

Willow Park, Chorley, Lancashire shown above, is laid out in plan and section to maintain solar access. The designers, TRADA Architects, describe it as follows: "The site planning involved finding a balance between the requirements for an informal layout suitable to a rural site and the rigid parameters of an optimum south orientation and a calculated north to south spacing to minimise overshading. This balance is achieved by the use of the gently curving main spine road with free form access roads from this."

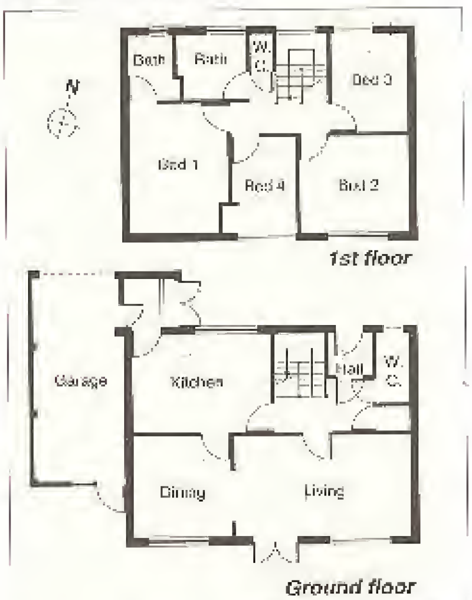


North-south section through site

Willow Park estate shows that an informal site layout can be achieved with the houses orientated towards the south.



Great Linford site plan.



Built in 1980, the Great Linford design recognised the prime importance of minimising heat losses, as well as a southerly orientation.

Great Linford, Milton Keynes

This development comprises eight detached houses each of 110 m² built by S & S Homes Ltd. The site plan shows the linear layout with the rear facades all facing 15° east of south. These southern facades are almost entirely unobstructed in their view of the sun.

The house plans illustrate many of the key principles of low energy house design:

- compact plan form
- main habitable rooms on the south side
- glazing concentrated on the south facade
- staircase, bathrooms, kitchen on north side
- garage as buffer to west facade
- utility room as draught lobby
- draught lobby to front door

The heating system was designed to be responsive to solar gains. It comprises a gas-fired boiler, which serves radiators that are controlled by thermostatic radiator valves. There are separate zones to the ground and first floor – each with its own air thermostat. The heat loss rate was equal to 1.95 W/K per square metre and space heating consumption 52 kWh/m² for 1981/83.

U-values (W/m²K)

	design	Building Regulations when designed
roof:	0.22	0.6
walls:	0.32	0.6
windows:	2.9	5.7
floor:	0.9	

Lifestyle 2000, Shenley Lodge, Milton Keynes

This house was designed, by TRADA Architects, to meet a Canadian energy performance target known as R2000. It is 150 square metres in area, and comprises a compact two-storey block with a single-storey extension forming the living room and an attached conservatory. Almost all the main habitable rooms share a southerly orientation, and north facing windows are kept to a minimum.

The planning has been described by its architect as follows. "The southern side of the house was conceived as a progression of spaces according to season: the cosy enclosed living room around the fire in the middle of winter; a move into the more open conservatory when solar gain takes effect in late winter and early spring; under the pergola in late spring as the plants and flowers bloom; and finally out into the private garden in summer."

Although windows are concentrated on the southern facade, they are modest in size. Larger glazing might carry the risk of overheating in this timber frame building, especially as the orientation is actually 29° west of south. Solar control in summer is achieved by eaves overhangs, planting on the pergola, and roof blinds in the conservatory.

Construction, shown opposite, is of timber frame. The whole of the building envelope is not only very highly insulated but also well sealed. All windows and external doors are draughtstripped.

U-values (W/m²K)

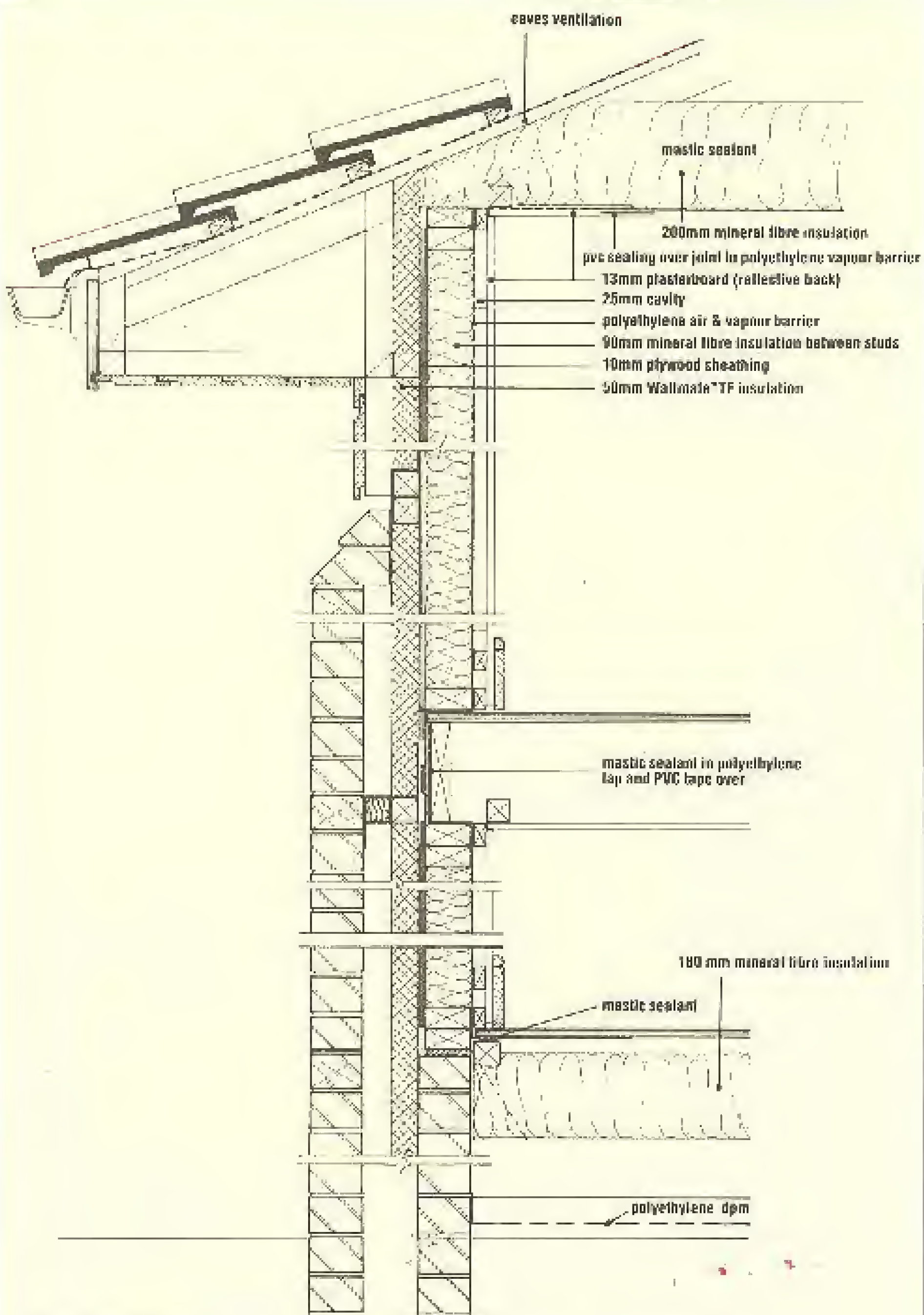
	design	Building Regulations when designed
roof:	0.25,0.19	0.35
walls:	0.20	0.6
windows:	1.9	5.7
floor:	0.23, 0.18	

The heat loss rate is calculated at 161 W/K, equivalent to 1.07 W/K per square metre of floor area.

To meet the energy performance target to which it was designed, air leakage of the house was checked. When pressure tested at 50 Pa, the air change rate per hour (ac/h) was found to be 1.7. Under normal conditions this is equivalent to just 0.1 ac/h when the house is occupied. Construction is exceptionally airtight in comparison to typical British practice.

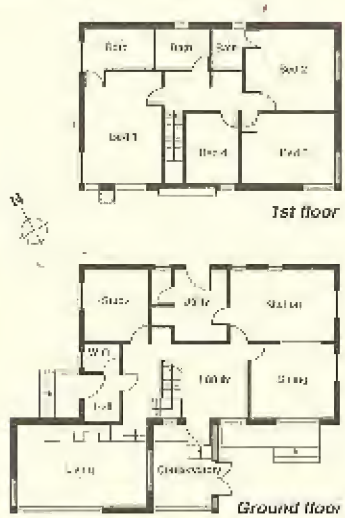
A mechanical ventilation system incorporates a heat exchanger in the roof space to remove heat from the air extracted from kitchens and bathrooms. Pre-warmed air from the conservatory is also ducted to the heat exchanger for winter operation.

The heating system is fairly conventional and uses a condensing boiler serving radiators with thermostatic radiator valves. Boiler output is controlled by a weather compensator. Space heating estimates based on fuel bills put the annual consumption at 2800 kWh, equal to 18.5 kWh/m². This represents about £56 per year (1993 prices).



*Trademark of the Dow Chemical Company

Attention to detail in order to achieve good insulation and airtight construction is one of the keys to energy efficient housing.



Lifestyle 2000 is airtight and well insulated and avoids overlarge south facing windows.

Courtyard Houses

These single-storey dwellings, designed by Feilden Clegg Architects, are of highly innovative form and specification. The plan is divided into a single aspect south facing block comprising the main living rooms, and a bedroom wing at right angles to it. This wing is linked to the next house in the row, resulting in the formation of a private courtyard for each house.

The spacing of the houses and the monopitched roof are designed to provide solar access to the fully glazed facades of the south facing block. The whole facade is in view of the sun when it is at its maximum altitude on the shortest day (the sun-path diagram in figure 1 can be used to work this out for houses at a latitude of 52° north).

Openable parts of these glazed facades are fitted with triple glazed sealed units incorporating two low-emissivity coatings and argon-filled cavities. This gives a U-value of 1.1 W/m²K. The non-openable parts have an additional pane of glass, resulting in a U-value of 0.9 W/m²K. These glazing systems offer improved heat loss characteristics, but their solar transmission is reduced to about 40%, compared with about 75% for double glazing and 87% for single glazing.

Automatic blinds, to prevent summer overheating, were installed in the first two houses, but were found to be unreliable and later houses use a pergola.

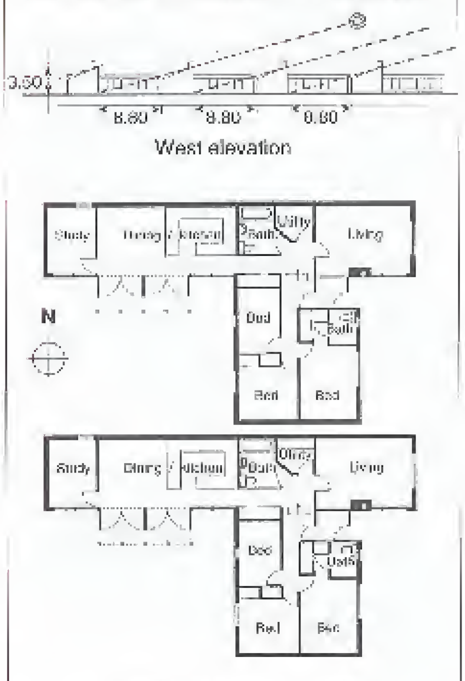
The heating system uses a gas fired condensing boiler serving radiators, and controlled by a boiler energy management system. The two wings are separately zoned. There is also a mechanical ventilation system.

U-values (W/m²K)

	design	Building Regulations when designed
roof:	0.21	0.35
walls:	0.27	0.6
windows:	0.9, 1.1	5.7
floor	0.27	

The total heat loss rate of the houses is 225 W/K, equal to 1.56 W/K per square metre of floor area. Detailed monitoring revealed that annual space heating consumption was 9360 kWh as an average figure for the heating seasons 1987/88 and 1988/89. This equates to 65 kWh/m², and it represents a space heating cost of £187 per year (1993 prices). Later versions of this house design built using only double glazing instead of quadruple used about 50% more fuel for space heating.

Maximum solar altitude for 22 December



Floor plan of two houses

The quadruple glazing reduced the amount of radiation transmitted and high internal gains reduced the usefulness of solar gains.

Lessons from the Case Studies

The Case Studies in this Guide have a number of common features. All the sites are arranged to allow good solar access. Floor plans place the main living rooms on southerly facades with, in most cases, the ancillary rooms on the north side. All have 100 mm or more of wall insulation, and at least 150 mm in the roof. They all have floor insulation (which was not compulsory under the Building Regulations at the time they were constructed). They all use double glazing or better. Air infiltration has been reduced (in some cases) to very low levels, and control gained over ventilation. Heating systems are designed to ensure incidental gains lead to fuel savings – not overheating.

The Courtyard House is, perhaps, the most radical and innovative in its attempt to exploit solar gains. It does so by its overall planning which allows large areas of high specification glazing without compromising privacy. But its internal arrangement necessitates a large ratio of exposed surface area to internal volume and its energy consumption for space heating is rather higher than, for example, the Lifestyle 2000 house, which uses a more compact plan form and even higher levels of insulation.

The Case Studies illustrate the benefits of a number of features which can be employed to design energy efficient houses.

- compact plan forms with a minimum of exposed surface area and, optionally, use of thermal buffering
- reductions in fabric heat losses achieved by high levels of wall, roof and floor insulation
- reductions in adventitious infiltration by construction measures which improve the airtightness of the envelope
- planning of sites and room layouts so houses benefit from solar gains
- consideration of the energy balance of windows – with north facing windows reduced in size, but without excessive increase in south facing ones
- adoption of high specification glazing systems to reduce heat losses where large windows are required.

Reference

Solar Energy and Housing Design
Volume 1: Principles, objectives, guidelines
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Volume 2: Examples
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Price £15.00
ISBN for the set: 1 870890 45 0
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EEO Best Practice programme, Good Practice Case Studies:

Case Study 90. Energy Efficiency in new housing incorporating passive solar design – Lewric Park Road.

Case Study 91. Energy efficiency in new housing incorporating passive solar design – Gifford Park.

Other EEO related publications

Passive solar design and housing, M Buckley, Architects' Journal, 9 June 1993, pps 23-6.

Further reading

Site Layout Planning for Daylight and Sunlight, BRE Report BR 209, PJ Littlefair, BRE, 1991
Price £40.00
Tel 0923 664444.

BS 8206 Lighting for Buildings Part 2: Code of Practice for Daylighting, BSI, 1992
Price £57.50
Tel 0908 221166.

Glass and Solar Heat Gains, Pilkington Glass Consultants
Tel 0744 692000.

Energy Conscious Design: a primer for architects, edited by J R Goulding, J O Lewis and T C Steemers, Batsford
ISBN 0 7134 69 19 8
Price £25.00
Tel 071 486 8484.

Energy in Architecture, the European Passive Solar Handbook, edited by J R Goulding, J O Lewis and T C Steemers, Batsford
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